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F1T
F2R
Selected US specifications from IPC sub-classes B64C F03D

(54) Wind turbine

(57) Enhanced aerodynamic lift of a wind turbine is achieved by providing each blade 12 of the turbine rotor with a longitudinally-extending pathway 14 which has an inlet 16 through which air can enter and flow through the pathway 14 and an outlet 26 located adjacent and substantially parallel to the leading edge of the blades. The outlet 26 is adapted to direct air flowing from the pathway over the blade surface towards the trailing edge of the blade 12. That flow of air adheres to the blade surface owing to the Coanda effect and, consequently, induces air flowing over the surface to accelerate thereby enhancing the aerodynamic lift experienced by the blade 12. Flow through pathway 14 may also comprise flow supplied via the rotor hub and may be controlled by valve 30 and a valve in the rotor hub. The valves may be operated by centrifugal force to close in an overspeed condition. The wind turbine may be of the horizontal or vertical axis type and the blades may be fixed or variable pitch, and twisted. Flow guides 28 may also be provided. The outlet 26 may extend over the outer 80% to 98% and the inlet 16, over the inner 5% to 35% of the blade radius.

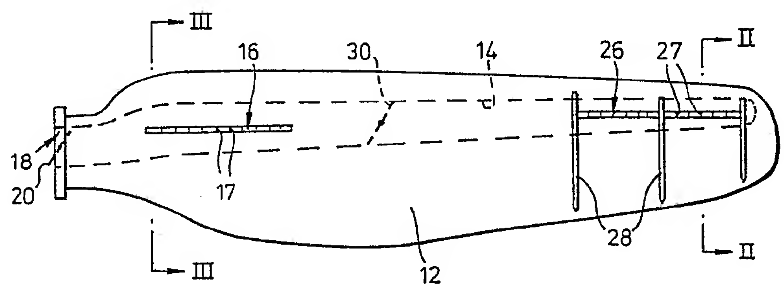

Fig.4.

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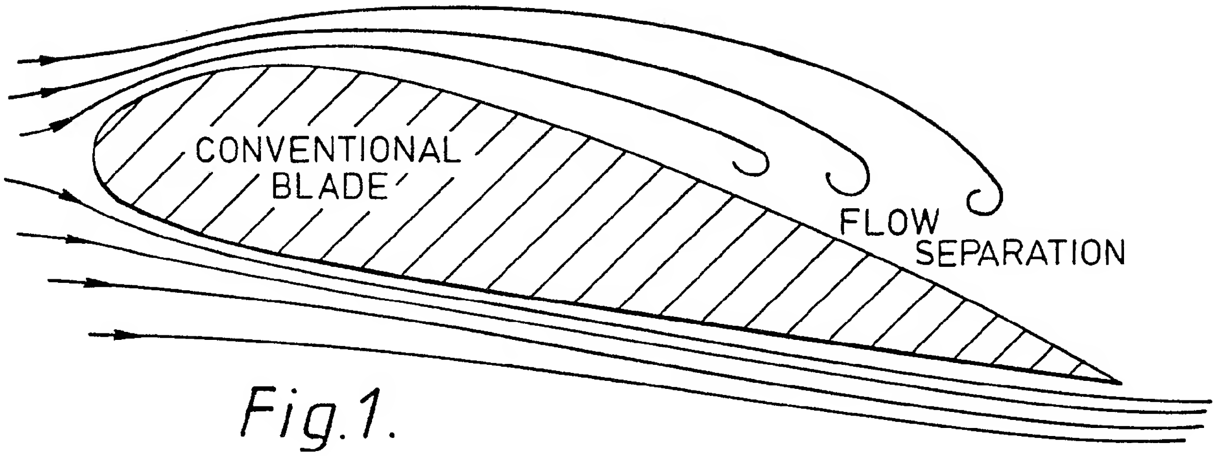

Fig.1.

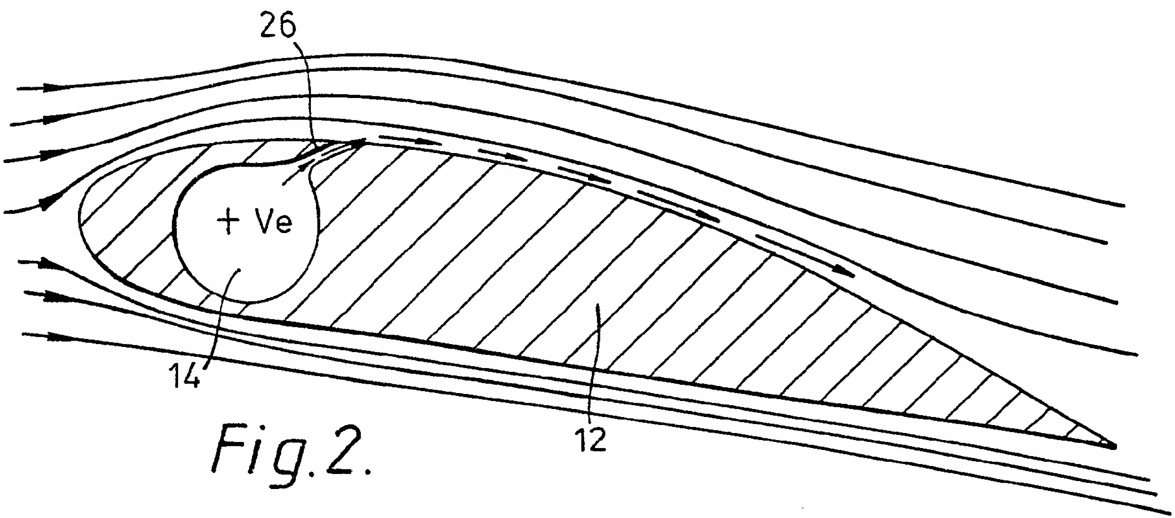

Fig.2.

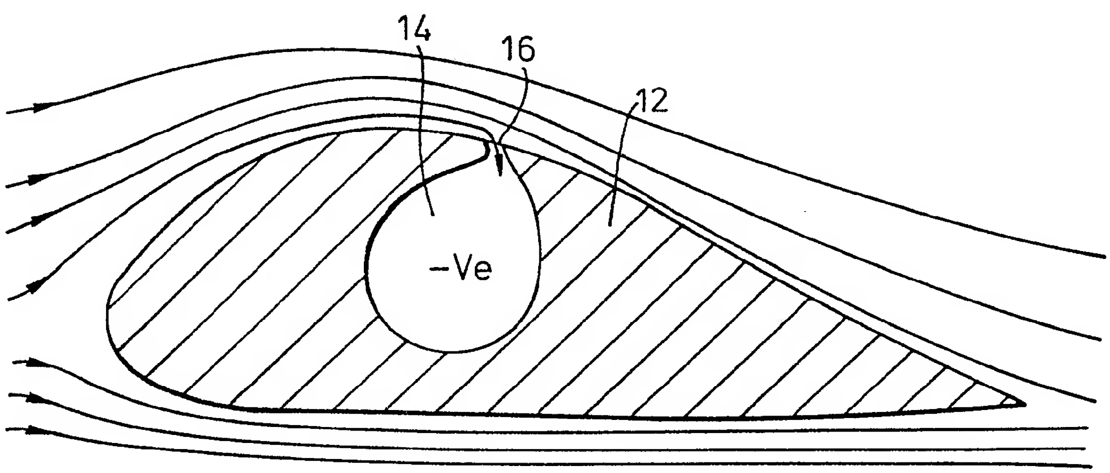

Fig.3.

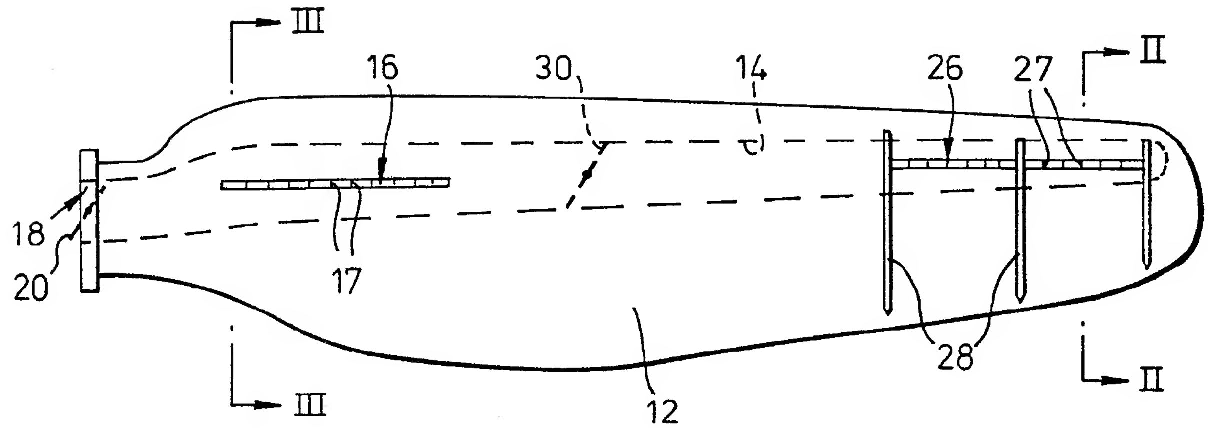

Fig.4.

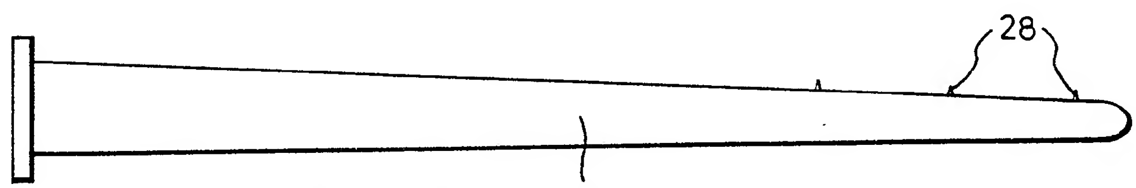

Fig.5.

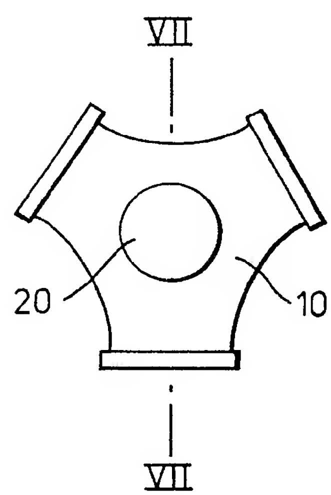

Fig.6.

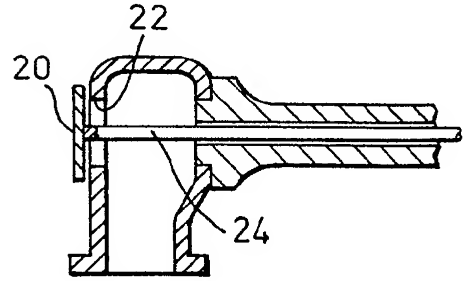

Fig.7.

SPECIFICATION

Wind turbine

The invention relates to a wind turbine particularly, though not exclusively, to a turbine having fixed-pitch blades.

To function effectively as a prime mover for electrical power generation, a wind turbine rotor should operate at a constant speed of rotation so that a simple fixed-ratio mechanical transmission may be used to turn the generator at a constant speed appropriate to the frequency of alternating current required e.g. 50 - 60Hz.

It is preferable to keep the construction of the turbine rotor simple using fixed-pitch blades secured, e.g. by being bolted, to the rotor hub. Such constructions apply particularly to smaller wind turbines having rotor diameters of 25m and below, but an effective technique for controlling the maximum speed of rotation of the rotor would no doubt enable this form of construction to be used on larger machines.

These requirements, which are directed to give reliability and minimum cost of construction and operation, create problems in operation. At present, these problems are solved in part by a compromise in the use of stall-regulated blade forms. Stall-regulated blade forms have less twist than would be required to give a constant angle of attack at all blade radii. The angle of attack at any given blade radius is defined as the angle between the pitch angle of the blade-section chord at that radius and the resultant wind vector formed by the vectorial addition of the circumferential blade velocity vector at that radius and the velocity vector of the wind. If the blade twist is such that at every section the angle of attack gives maximum lift (approximately 12-16°) at some nominal wind speed and speed of rotation, then a slight increase in wind speed would stall the whole blade and a dramatic reduction of aerodynamic lift and hence torque and power would occur. By designing the blade such that the blade root section is at a steeper angle of attack than the tip, stall can be made to develop progressively at greater and greater radii as the wind speed increases and thus producing an approximately constant power over a range of wind speeds.

In very high wind speeds, the power begins to increase once more and, since the increase is largely produced by wind pressure reaction on the flat surface of the blade, it is difficult to control except by spoilers, airbrakes or other movable surfaces.

Also, it is necessary to keep the blade pitch flat to reduce the torque produced by wind pressure.

As a consequence, wind turbines having fixed-pitch blades, particularly stall-regulated blade forms, have poor starting characteristics in light winds.

Although the above description refers specifically to horizontal axis turbines, it will be readily apparent that vertical axis turbines having fixed-pitch blades (whether fixed or variable tilt angle blades) can also have poor starting characteristics in light winds for similar reasons.

According to the present invention, a wind turbine comprises a rotor having at least one blade in the form of an aerofoil and valve means, the blade having an internal pathway which extends generally parallel to the longitudinal axis of the blade and which has an inlet through which air can enter and flow along the pathway and an outlet located adjacent and substantially parallel to the leading edge of the blade, the outlet being adapted to direct air flowing from the pathway over the blade surface towards the trailing edge of the blade thereby enhancing the aerodynamic lift experienced by the blade, flow of air along the pathway to the outlet being controllable by said valve means.

Preferably, the blade is a fixed-pitch blade.

Preferably, the rotor is mounted on a horizontal axis. In that instance, the outlet is located between the midpoint and the tip of the blade, preferably over the outer 80% - 98% of the blade radius as measured from the root of the blade. The inlet is located in the radially inner part of the blade. In one embodiment, the inlet is in, and is substantially parallel to the longitudinal axis of the blade and preferably extends over the inner 5% - 35% of the blade radius as measured from the root of the blade. The inlet is adapted to receive air into the pathway from the blade surface to augment laminar flow over the blade surface thereby enhancing the aerodynamic lift experienced by the blade. Alternatively, or additionally, the inlet extends radially through the root of the blade.

Alternatively, the rotor is mounted on a vertical axis.

The invention also includes a wind turbine blade as defined in the preceding three paragraphs.

A wind turbine will now be described to illustrate the invention by way of example only with reference to the accompanying drawings, in which:-

Figure 1 is a cross-section of a conventional wind turbine blade, the air flow pattern over the blade at the onset of stall being shown by the flow lines;

Figures 2 and *3* are cross-sections taken on lines II - II and III - III, respectively, of the blade shown in Figure 4, the air flow patterns over the respective cross-sections of the blade being shown by the flow lines;

Figure 4 is a schematic elevation of a wind turbine blade constructed in accordance with the present invention;

Figure 5 is a schematic side view of the blade shown in Figure 4; and

Figures 6 and *7* are a schematic elevation and section taken on a line VII - VII in Figure 6, respectively, of the hub of the turbine showing one form of valve arrangement.

An horizontal axis wind turbine (not shown) has a rotor (not shown) connected through a transmission (not shown) to a generator (not shown).

The rotor of the turbine has a hub 10 (Figures 6 and 7, for example) to which are bolted three equi-angularly-disposed blades 12 (Figures 4 and 5) which are aerofoils. The blades 12 are preferably twisted such that the turbine is stall regulated. However, for simplicity the twist of the blades 12 is not shown on the drawings.

Each blade 12 has an internal pathway 14 extending generally parallel to the longitudinal axis of the

blade 12 and from the radially inner end of the blade 12 to a position immediately adjacent the tip of the blade 12. Each blade 12 has an inlet into the respective pathway 14 in the form of a slot 16 extending over approximately 5% - 35%, for example, of the radius of the blade 12 measured from the root of the blade 21. As is explained more fully below, air is sucked into the pathway 14 through the slot 16 as indicated in Figure 3.

Each blade 12 has a second inlet 18 through the root of the blade 12. Air flow through the inlet 18 is controlled by a valve shown diamgrammatically at 20 in Figure 4. In practice, the valve 20 is, for example, a common valve regulating an opening 22 in the hub 10 and being operable by a control rod 24, the inlets 18 of the blades 12 all communicating with the interior of the hub 10.

Each blade 12 has a corresponding outlet out of the respective pathway 14 in the form of a slot 26 located between the midpoint and the tip of the blade 12 and, typically, extending between approximately 80% - 98% of the radius of the blade 12 measured from the root of the blade 12. The slot 26 is adjacent and substantially parallel to the leading edge of the blade 12 and is adapted to direct air flowing from the pathway 14 over the blade surface towards the trailing edge of the blade 12 as indicated in Figure 2.

Preferably, flow guides 28 extend transversely over the blades 12 to ensure the air flows transversely of the blade 12 in the region of the outlet slots 26.

The slots 16 and 26 have respective stream-lined stiffening ribs 17 and 27, respectively, extending across them to reinforce the blades 12.

The air flow along each pathway 14 is regulated by a respective control valve 30, the valves 30 of the blades 12 being interconnected for simultaneous operation.

The operation of the turbine will now be described.

When the rotor of the turbine is rotating, the mass of air within the pathway 14 in each blade is subjected to centrifugal force which results in an increase in pressure at the blade tip and a decrease in pressure at the blade root.

Owing to the increase in air pressure at the blade tips, the air is forced out of the respective slots 26 and over the respective blade surfaces at a relatively high velocity towards the respective trailing edges of the blade 12 (see Figure 2). The flows of air over the blade surfaces adheres to those surfaces owing to the Coanda effect and, consequently, induces the air stream flowing over the blades 12 to accelerate thereby enhancing the aerodynamic lift experienced by the blades 12.

The decrease in pressure at the respective blade roots results in air being sucked through the respective slots into the respective pathways 14 (see Figure 3). The suction of air into the respective slots 16 augments the laminar flow of the air stream over those sections of the blades 12 thereby enhancing the aerodynamic lift experienced by the blades 12.

When additional air mass flow is required to maximise the flow of air along the pathways 14 and out of the slots 26, the valve 20 is opened whereby air is drawn into the pathways 14 through the hub 10.

The valves 20 and 30 are centrifugally-operable to close the inlet opening 22 and the pathways 14, respectively, when the wind speed is sufficient to force the turbine into an overspeed condition. The valves 20 and 30 are also preferably controlled to decrease the flow of air through the slots 26 gradually over a range of wind speeds thereby reducing the lift experienced by the blades 12. Such a reduction in lift limits the power generated by the turbine. Once the air flow from the slots 26 is reduced sufficiently, the blades 12 will experience stall owing to the separation of the boundary layer from the blade surface in a similar manner to a conventional blade as shown in Figure 1.

The reduction in power generation achieved by the use of valves 20 and 30 renders the turbine more amenable to shutdown by conventional retarding systems such as electrodynamic braking and mechanical brakes.

When the valve 20 is opened, the amount of air flowing into the pathways 14 through the slots 16 is reduced. If required, however, partitions can be placed in the pathways 14 relative to the slots 16 such that air flow along the pathways 14 from the hub 10 induces inward air flows through the slots 16.

The enhancement of aerodynamic lift achieved by the provision of the outlet slots in the region of the blade tips enables the blade chord to be reduced significantly, particularly in the tip region but also to some extent over the whole of the length of the blade. This feature taken together with control available owing to the regulating effect of the valves 20 and/or 30 means there is less constraint on the permitted pitch angles of the blade at various radii. Consequently, blades constructed in accordance with the present invention can have more twist (as compared to a conventional blade) thereby giving an improvement in the starting characteristics of the turbine whilst still being able to derive the required power from the wind.

Furthermore, the reduced blade chord means the turbine has a lower solidity factor (i.e. ratio of area of blades the area swept by blades) which gives a higher efficiency for the turbine. Also, in limiting wind conditions, the lower solidity factor means the turbine has a reduced thrust reaction and thus a lower maximum storm overturning moment thereby leading to a saving of materials in the construction of the tower.

The use of the inlet slots 16 to enhance the aerodynamic lift experienced by the blades 12 allows the blade root section to be increased as compared to a conventional blade root section. The increased blade root section will reduce stress levels in the blade structure thereby leading to a saving in materials.

Modifications are possible within the scope of the invention. For example, air under pressure could be supplied to the inlets 18 to provide a flow of air from the outlet 26 even when the rotor is at rest. That provision would improve the starting characteristics of the turbine. In those circumstances, the inlet slots 16 would not be provided (since the pressurised air would flow out of the slots 16); or, alternatively, the outlet 26 would be segregated into two sections connected by separate pathways 14 to the inlet slots 16

and to the inlets 18, respectively. In other modifications, only one of the inlets need be provided, preferably the inlet 18. The invention is also applicable to untwisted blades.

The invention is also applicable to turbines having variable-pitch blades. When the pitch of such blades is changed, a surge in the power generated by the generator is usually experienced as the blades move from a stalled condition to a power-generating condition. The valve means can be used to minimise the lift augmentation provided by the invention during the pitch change of the blades thereby to minimise such power surges.

In another form (not shown), the invention is applicable to vertical axis wind turbines. In that instance, the air is subjected to centrifugal forces in the rotor arms on the ends of which are mounted the blades. Additionally, air can be positively blown through the arms. When the blades are mounted on the arms at an angle to the axis of rotation (i.e. the tilt angle), preferably the outlets are limited to those parts of the blades radially outwardly of the end of the rotor arms.

CLAIMS

1. A wind turbine comprising a rotor having at least one blade in the form of an aerofoil and valve means, the blade having an internal pathway which extends generally parallel to the longitudinal axis of the blade and which has an inlet through which air can enter and flow along the pathway and an outlet located adjacent and substantially parallel to the leading edge of the blade, the outlet being adapted to direct air flowing from the pathway over the blade surface towards the trailing edge of the blade thereby enhancing the aerodynamic lift experienced by the blades, flow of air along the pathway to the outlet being controllable by said valve means.

2. A wind turbine according to claim 1, in which the rotor is mounted on a horizontal axis, the outlet being located between the midpoint and the tip of the blade and the inlet being located in the radially inner part of the blade.

3. A wind turbine according to claim 2, in which the outlet extends over the outer 80% - 98% of the blade radius as measured from the root of the blade.

4. A wind turbine according to claim 2 or claim 3, in which the inlet is in, and is substantially parallel to the longitudinal axis of, the blade and is adapted to receive air flowing over the blade surface to augment laminar flow over the blade surface thereby enhancing the aerodynamic lift experienced by the blade.

5. A wind turbine according to claim 4, in which the inlet extends over the inner 5% - 35% of the blade radius as measured from the root of the blade.

6. A wind turbine according to any one of claims 2 to 5, in which the inlet or a second inlet extends radially through the root of the blade.

7. A wind turbine according to any one of the preceding claims, in which the blade is a fixed-pitch blade.

8. A wind turbine according to claim 1, in which the rotor is mounted on a vertical axis.

9. A wind turbine according to any one of the preceding claims, in which the valve means close automatically if the rotor is in an overspeed condition.

10. A wind turbine according to any one of the preceding claims in which flow guides extend transversely of the blade in the region of the outlet thereby to guide air transversely of the blade in said region.

11. A wind turbine according to claim 1 substantially as hereinbefore described with reference to Figures 2 to 7 of the accompanying drawings.

12. A wind turbine blade as defined in any one of the preceding claims.

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